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The Emotional Attentional Blink: A review and research agenda

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Abstract

The Emotional Attentional Blink (EAB) refers to a temporary impairment in the ability to identify a single target when that target is preceded by an emotionally salient distractor, such as a disgusting, violent or erotic image (Most, Smith, Cooter, Levy, & Zald, 2007; Ciesielski, Armstrong, Zald, & Olatunji, 2010). The EAB represents a failure to perform an endogenous target discrimination task as a result of exogenous attentional capture by an emotional image, making it an effective medium through which to study the intersection of these two attentional systems. The present review seeks to relate existing models of the EAB to models of emotion (Tamietto & de Gelder, 2010) as well as endogenous and exogenous attention (Corbetta & Shulman, 2002; Taylor & Fragopanagos, 2005) in order to demonstrate the EAB's utility in these research fields. Accompanying this review will be a brief research agenda and pilot experiment meant to address a few of the most integral questions to the study of attention and emotion, utilizing the EAB paradigm. A review of relevant literature as well as the aforementioned pilot study support the notion that the EAB may be a powerful tool in uncovering answer to the bigger questions in attention and emotion research.

We are constantly bombarded with information from our environment, forcing us to allocate our limited neural resources towards processing what may be most important. This process is typically behaviorally advantageous, as it allows us to selectively attend to the most significant information in the environment while ignoring the insignificant. However, sometimes this process fails. One example of this failure is the Emotional Attentional Blink.

The Emotional Attentional Blink (EAB) refers to a temporary impairment in the ability to identify a single target when that target is preceded by an emotionally salient distractor, such as a disgusting, violent or erotic image (Most, Smith, Cooter, Levy, & Zald, 2007; Ciesielski, Armstrong, Zald, & Olatunji, 2010). The typical EAB paradigm consists of a single target image, a landscape or building turned 90 degrees either clockwise or counterclockwise, embedded within a rapid serial presentation of behaviorally irrelevant landscape images (e.g. Figure 1a; Most, Chun, Widders, & Zald, 2005; Piech, Pastorino, & Zald, 2010; Olatunji, Ciesielski, Armstrong, Zhao, & Zald, 2011; Piech et al., 2011). When an emotional distractor precedes the target image by roughly 100-600 ms, there is a significant decrement in participants' ability to report the direction that the target was turned when compared to the presentation of a neutrally valenced distractor, as exemplified in Figure 1b (i.e. EAB; Most & Jungé, 2008; Ciesielski et al., 2010).

This phenomenon is not the result of categorical distinctiveness (Kennedy & Most, 2015) or low level images differences such as color, as scrambled negative critical distractors did not create a decrement in performance on the target identification

task (Most et al., 2005). Additionally, the EAB does not diminish over repeated presentations of the emotional critical distractor (McHugo et al., 2013) as is observed in Surprise-induced Blindness (SiB) studies (Asplund, Todd, Snyder, Gilbert, & Marois, 2010), which utilize a categorically salient but task-irrelevant distractor in a single-target RSVP paradigm. In SiB studies, participants are not informed that this categorically salient distractor will be presented. Therefore, the exogenous attentional capture of the distractor, and the subsequent decrement in task performance, is attributable to its unexpected nature (Asplund et al., 2010). Conversely, despite participants being informed that there will be categorically and emotionally salient distractors within the RSVP paradigm of the EAB, they are not able to resist exogenous attentional capture by emotionally-salient distractors creating a deficit in target discrimination. This is not the result of surprise, as participants are informed of all images that they will observe, or categorical salience, as the categorically-salient neutral critical distractors do not elicit this deficit in target discrimination.

Therefore, this effect is directly attributable to the emotional nature of the critical distractor, though situationally variable in magnitude or appearance based upon characteristics of the images or the participants. There are observable differences in the magnitude of the EAB associated with clinical populations (e.g. Generalized Anxiety Disorder, Obsessive Compulsive Disorder) in comparison to typical healthy individuals (Olatunji et al., 2011a; Olatunji et al., 2011b) and individual differences in harm avoidance (Most et al., 2005). Additionally, veterans with PTSD exhibit an EAB to war images that is not present in non-military individuals (Olatunji et al., 2012). More

transient states even have measurable effects on the EAB, as fasting can lead to participants demonstrating an EAB to food images (Piech et al., 2009) and stimuli can be conditioned with a loud noise to elicit an EAB (Smith, Most, Newsome, & Zald, 2006). These studies extend the contention that arousal, rather than valence, is the driving factor behind the attentional capture of the critical distractor (McHugo, Olatunji, & Zald, 2013) as has been asserted independently in studies involving passive viewing of emotional images (Bradley et al., 2003), the traditional attentional blink (Kiel and Ihssen, 2004), and emotional stroop tasks (Arnell, Killman, & Fijavz, 2007).

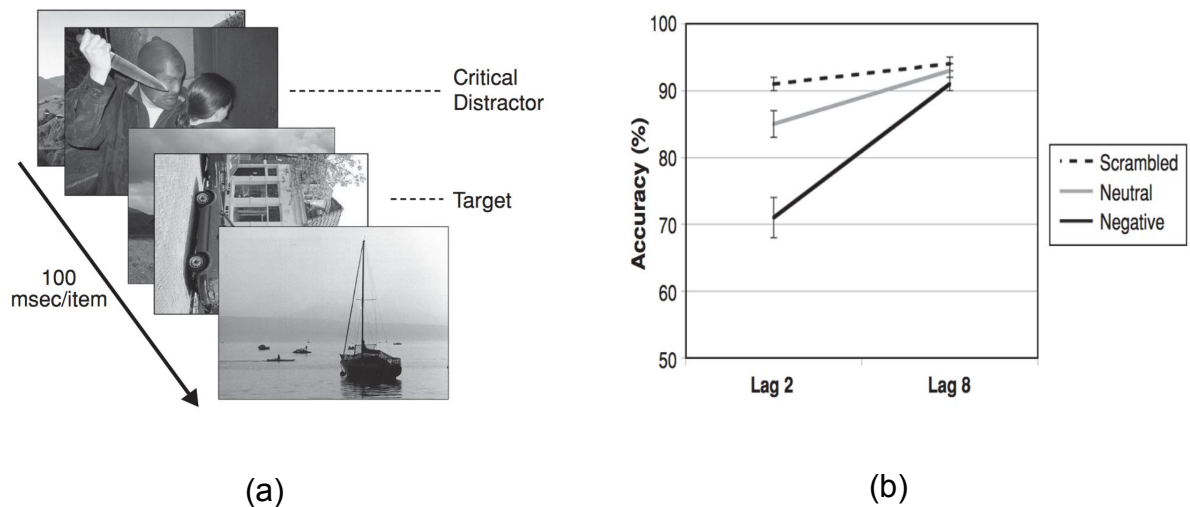


Figure 1. (a) An example of a portion of an EAB paradigm. The critical distractor here is a violent image preceding the target image, the turned landscape, by two images (lag 2). (b) Accuracy data demonstrative of the presence of an EAB. Performance in the presence of a negative critical distractor is significantly worse than a neutral critical distractor at lag 2, but there are no significant differences at lag 8. (both figures from from Most et al., 2005)

The differential characteristics of the EAB based upon clinical disorders or even transient states of the participants demonstrate its possible utility as a tool in studying

the effectiveness of interventions or even better characterizing the neural mechanisms underlying psychological disorders (McHugo et al., 2013). However, the EAB has the potential to be even more useful in cognitive studies of attention and affect. The EAB represents a failure to perform a top-down attentional task due to bottom-up attentional capture, which makes it helpful in uncovering the underlying mechanisms of both endogenous and exogenous attention. Modeling the EAB and extending findings to pre-existing theories of neural networks governing endogenous and exogenous attention may yield important information regarding how the two systems work together, and at times against each other, to shape perception. Additionally, the EAB may be used as a tool to study differential processing related to the affective qualities of stimuli in order to better characterize how emotional information is processed in the brain. In order to extend these findings and fully utilize the paradigm, we must first gain a better conceptual understanding of exactly how the EAB arises.

Models of the EAB

The EAB has previously been explained within the context of a two-stage model originally proposed for the traditional Attentional Blink (i.e. AB; Chun & Potter, 1995) and extended to the EAB (Most & Junge, 2008). The Attentional Blink (AB) is the transient cost in reporting the second of two targets, when the latter target (T2) appears approximately 200 - 500 milliseconds after voluntarily attending to the first target (Raymond, Shapiro, & Arnell, 1992; Chun & Potter, 1995; Giesbrecht & DiLollo, 1998). This two-stage model proposes an initial high-capacity stage 1 buffer that creates weak representations of all stimuli, which then compete for resources required for

consolidation at a limited capacity stage 2. These stage 2 resources are necessary to form a stable and conscious target percept. In the context of the AB, the deficit in T2 identification is theorized to occur because of the voluntary overinvestment of limited-capacity resources to the processing of the first target, leaving insufficient resources for the attention to or consolidation of the second target (Olivers & Nieuwenhuis, 2006). In the context of the two-stage model, the emotional critical distractor is theorized to involuntarily capture the central resources necessary to discriminate the single target's orientation, preventing its transient representation from being consolidated for report in stage 2 (Most & Junge, 2008).

However, the EAB is distinct from the AB in several important ways. The EAB, which utilizes only a single-target paradigm, is a deficit in an endogenous target identification task as a result of exogenous attentional capture. For this reason, the EAB is an effective medium through which to study both endogenous and exogenous attention and their interactions, whereas the AB is typically characterized as indicative of endogenous attentional limitations. Additionally, there are several indicators that the AB and EAB represent distinct processes. The AB demonstrates lag 1 sparing that is not observed in the EAB (McHugo et al., 2013). Furthermore, the EAB is dependent upon the spatial alignment of the emotional critical distractor and the target (Most & Wang, 2011), whereas the AB persists across spatial locations (Jiang & Chun, 2001). Therefore, though the two-stage model is appropriate for both phenomena, it is important to consider other explanations regarding the occurrence of the EAB.

A separate, but complementary, model posits that distinct emotional processes occur in parallel to those associated with voluntary attention to pre-attentively weight the emotional distractor of the EAB paradigm such that it is consolidated more readily (Ciesielski et al., 2010; Most & Junge, 2008; Most & Wang, 2011). This preattentive prioritization is commonly proposed within affective research utilizing a number of different paradigms and phenomena (Robinson, 1998). In visual search, this process manifests itself as a faster response time to emotional than neutral targets that persists despite increasing set size and quickens as a function of participant's phobia of the target (Ohman, Flykt, & Esteves, 2010). This is suggestive of the presence of a search process working more quickly in parallel (Müller, Anderson, & Keil, 2008). Alternatively, this process may be characterized as a "relevance check" that dictates how attention is allocated in the immediate future based upon the salience of the presented stimuli (Scherer, 2001; Schimmack & Derryberry, 2005) in the course of an emotional stroop task (Arnell et al., 2007). It is unclear exactly how this preattentive process accomplishes the prioritization of emotional stimuli, but some suggest that it may be the result of changes in low-level image feature preference (Phelps, Ling, & Carrasco, 2006; Bocanegra & Zeelenberg, 2009) or general perception mediated by projections from the amygdala to visual cortices (Bradley et al., 2003; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). However, it is likely that the amygdala works in the context of a greater neural network responsible for this role.

Emotional Processing in the Context of a Dual-pathway Model of Attention

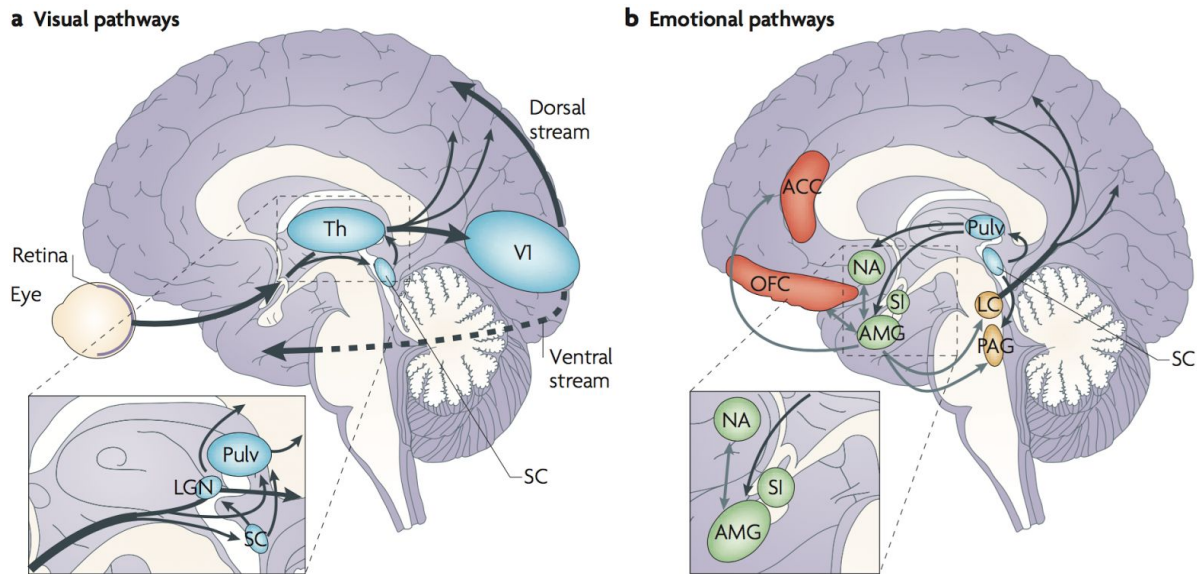


Figure 2. (a) Proposed pathways responsible for both exogenous and endogenous attention, with differentiated dorsal and ventral streams as proposed by Corbetta and Shulman (2002). (b) Proposed pathways responsible for the processing of emotional stimuli and resulting attentional changes. The amygdala plays a central role in this model, receiving information from earlier and later areas and sending information through both feed-forward and feedback projections. Arrow size in both figures is scaled to represent the density of projections. (from Tamietto & de Gelder, 2010).

Conceptual models and neuroimaging findings can work together in this case to better characterize both the phenomena and the neural pathways responsible for the processing of emotional and nonemotional information. It has been suggested that there are separate neural pathways projecting from the occipital lobe responsible for top-down and bottom-up attention, with the former taking a dorsal route to the frontal lobe through the parietal cortex and the latter taking a right hemisphere-lateralized ventral route to the same location through the temporoparietal junction (Corbetta & Shulman, 2002). Missing from this model, however, is a specific account of how emotional stimuli in particular may act to exogenously reorient attention within the context of this dual-network theory.

A complementary model (seen in figure 2) by Tamietto and de Gelder (2010) implicates a subcortical pathway for the processing of emotional stimuli, with the amygdala sending both feed-forward projections to frontal brain regions and feedback projections to regions of the brainstem in order to create holistic perceptual changes. The amygdala is a likely candidate for this role, as it has been demonstrated to modulate early visual processes in the presence of emotional stimuli in humans (LeDoux, 2000) and give rise to feedback projections to all levels of the ventral stream in the macaque brain (Amaral, Behniea, & Kelly, 2003). One alternative suggestion, compatible with the above claims, is that these dissociable ventral and dorsal pathways converge in the prefrontal cortex and integrate in the anterior cingulate gyrus to coordinate actions across the two systems (Yamasaki, LaBar, & McCarthy, 2002).

Taylor & Fragopanagos (2005) propose the most all-encompassing of these models, suggesting that the dorsal and ventral circuits work together through direct connections and the limbic circuit (including the amygdala) creates changes in both of these streams. These changes are made possible by direct connections with the ventral stream as well as connections between the orbitofrontal cortex and dorsolateral prefrontal cortex. While this model is compelling in its scope and compatible with the models of both Corbetta & Shulman (2002) and Tamietto & de Gelder (2010), it lacks the implication of specific neural areas that are proposed in these models. Importantly, each of these models proposes the concept of separable endogenous and exogenous attentional networks that converge to create holistic changes in the brain as a result of top-down task demands or attentional capture by emotional images.

Outstanding Questions

It is clear, then, that there are several outstanding questions about the mechanisms underlying the EAB and the nature of emotional processing as a whole. Several of these questions may be answered by a brief, effective research agenda utilizing the EAB paradigm. My proposed agenda begins by studying the neural mechanisms that underlie the EAB in order to more effectively understand the phenomenon and interpret further findings. With this exploratory electrophysiological study, I will also address one of the questions most central to this review: Does the prioritization of emotional images occur pre-attentively or at a central bottleneck? I will study whether this prioritization is the result of subcortical activity, as was suggested in several of the previously mentioned models. Finally, I will attempt to causally implicate regions of the cortex in the EAB with the use of TMS. As a whole, this research agenda should help to better characterize both the EAB and more general processes that result in attentional capture by emotionally salient images, laying out three distinct directions that researchers may take to pursue this goal.

Experiment 1

Introduction

The electrophysiological bases of the EAB are relatively unexplored and have the potential to reveal important information about the mechanisms that underlie the EAB. An electroencephalogram (EEG) study may be able to help address the first of these outstanding questions - what neural mechanisms may underlie the EAB - by allowing researchers to measure changes of electrical potential in the brain and relate those

changes to behavioral data. By collecting extensive EEG data and averaging activity in response to certain events, in this case the critical distractor and target of the EAB paradigm, it is possible to compute an Event-related Potential (ERP). The study of these ERPs is extensive, and measuring the magnitude of certain well-researched ERP components related to different neurological processes allows for study of the neural bases of phenomena. This route of research would allow for direct measurement of the neural activity related to the performance of the task and perception of the emotional critical distractor, studying for the first time what the underlying mechanisms of the EAB may be and also directly testing existing theory. Therefore, an exploratory EEG study is an appropriate starting point for this research agenda, providing context for the following studies.

The sole prior electrophysiological study of the EAB utilized negatively valenced critical distractors in the context of the typical EAB paradigm, focusing upon differential magnitudes of the N2 and P3b components between the critical distractor and target (Kennedy, Rawding, Most, & Hoffman, 2014). The authors found that emotional critical distractors elicited significantly larger N2 and P3b component magnitudes, thought to be indexes of selective attention and target consolidation to working memory respectively (Luck & Kappenman, 2011), in comparison to the presentation of neutral critical distractors. Interestingly, the magnitude of these components in response to the presentation of the emotional critical distractor varied inversely in comparison to the magnitude of the same components in response to the target. This is indicative of a trade-off between distractor and target processing at a late stage.

However, this study leaves several questions unanswered that may be addressed by the present experiment. It is worthwhile to study how erotic images, the only positively valenced images to elicit an EAB, may differ in the neural activity they elicit in the course of the paradigm. Erotic images typically elicit event-related potential (ERP) activity distinctive from that of negatively valenced images, including a larger and more sustained Late Posterior Positivity in tasks in which they are irrelevant (Weinberg & Hajcak, 2010) and a greater P3b amplitude in oddball tasks where participants are asked to respond to the erotic image (Briggs & Martin, 2009).

Beyond differences in processing related to distractor valence, there are also more general theoretical questions that merit addressing. Studying differences in the early ERP components thought to represent perceptual processing, such as P1 and N1, and relating their magnitude and time course to the same characteristics of the later components related to attentional processing, such as the aforementioned N2 and P3b, may allow for characterization of the pre-attentive mechanisms proposed earlier in this review. Several studies have demonstrated that P1, an early ERP component that may represent sensory processing or possibly an early locus of attention (Luck et al., 1994), is modulated by the emotional content of images (Müller et al., 2008; Schupp, Junghofer, Weike, & Hamm, 2003; Hot et al., 2006). Additionally, there is evidence that emotional images elicit a larger N1, thought to reflect more extensive early visual processing of emotional content (Hajcak, Weinberg, MacNamara, & Foti, 2012), to both positively and negatively valenced emotional stimuli in comparison to neutral images (Weinberg & Hajcak, 2010; Carretie, Hinojosa, Albert, & Mercado, 2006). By computing

difference waves between emotional and neutral trials and comparing across trials in which an accurate or inaccurate response was given, it is possible to discern what effect the emotional content of the critical distractor may have irrespective of activity resulting from simple salience of or attention to the critical distractor.

If the exogenous attentional capture of the emotional critical distractor in the EAB is indeed the result of a parallel, pre-attentive process responsible for prioritizing the stimulus for attentional resources, then there will be differences in the early P1 and N1 components in response to the onset of the critical distractor. These early changes should correlate with changes in later components more commonly accepted as indicative of attentional processing and stimulus consolidation, such as N2 and P3, when the emotional image prevents accurate target report. Alternatively, if the EAB is solely the result of a central bottleneck of resources related to close temporal proximity between the emotional critical distractor and target, then a relationship between the magnitudes of the later attentional components in response to the critical distractor and target should exist independently of any correlations with early sensory components. These objectives make the present experiment novel as a pilot study, testing whether the EAB is worth further pursuing as a paradigm in the context of an EEG study while also allowing for an attempt at replicating findings of the previous study.

Method

Participants

5 participants (ages 19-22; 2 female) from the University of South Carolina community participated in the 2 hour-long study and received course credit for their

efforts. Each participant provided informed written consent prior to the study's start, as per University of South Carolina Institutional Review Board (IRB) guidelines.

Participants were informed of the nature of visual stimuli they would be viewing.

Stimuli

A gray fixation box, $0.12^\circ \times 0.12^\circ$ in size, appeared in the center of the screen prior to and during each trial, against a uniform gray background. Stimuli consisted of color photographs sampled from 56 erotic images, 56 neutral pictures, 256 upright landscape/architectural scenes, and 244 target images (122 landscape/architectural photos rotated 90 degrees to the left and right). Landscape images were drawn from the set used by Most et al. (2005), and neutral images were drawn mostly from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). Emotional distractors consisted of erotic images drawn partly from the IAPS and supplemented with images drawn from the Internet (Most et al., 2007). The erotic pictures included images of nude couples engaging in sexual acts, whereas the neutral distractor images consisted of portraits depicting one person or several people in everyday settings and were rated as eliciting no emotional reaction. Stimuli were $11.7^\circ \times 7.9^\circ$ of visual angle in size and were presented on a 23-in. (58.42-cm) 100-Hz Digital LCD monitor via Presentation.

Procedures

A spacebar press began each block, initiating a rapid serial visual presentation (RSVP) of 17 images presented at fixation for approximately 100 ms each, an example of which is shown in Figure 1. Participants were instructed to keep their eyes fixed on a

fixation box at the center of the screen throughout each experimental trial. All images on a given trial consisted of different upright landscape/architectural photographs except for two: the critical distractor and the target stimulus. The critical distractor was displayed as either the fourth or sixth stimulus in the RSVP, and was either a neutral valence image of everyday interactions of people or an emotionally salient image of a nude couple engaged in erotic acts. The target was presented at a lag of either 2 or 8 images after the critical distractor (~200 ms or ~800 ms), and consisted of a landscape/architectural scene rotated 90 degrees clockwise or counterclockwise from vertical. At the end of each trial, participants were asked to identify which direction the target was turned, if a target was presented on that trial, using the 1 through 3 keys on the number pad. One third of trials did not contain a critical distractor while an independent third of trials did not contain a target; these images were replaced by a randomly-selected landscape distractor in order to create an effective baseline condition for EEG analysis. Participants performed a short practice block with coaching by the experimenter prior to the experiment. Each participant completed 24 experimental blocks consisting of 36 trials, presented successively in the center of screen with a random amount of time between 1 and 1.5 seconds between trials.

Electrophysiological Recording and Analysis

EEG data were collected using a customized 32-channel Brain Products ActiCAP electrode cap with electrodes positioned at AF3, AFz, AF4, FC5, FC3, FC1, FCz, FC2, FC4, FC6, CP5, CP3, CP1, CPz, CP2, CP4, CP6, PO11, PO9, PO7, PO3, POz, PO4, PO8, PO10, PO12, I1, Iz, I2, Ilz, M1, and M2. All EEG signals were referenced to the

right mastoid (M2). The horizontal electrooculogram (HEOG) was recorded bipolarly using two electrodes positioned lateral to the external canthi. Electrode impedances were kept below 20 k Ω . All signals were recorded unfiltered in DC mode using the Brain Products ActiCHamp amplifier, digitized at 500 Hz, and recorded using Brain Products PyCorder software (v. 1.6).

EEG pre-processing, artifact rejection, and ERP averaging were performed using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014). The raw EEG signals were filtered with a bandpass of 0.01 - 30 Hz (-3 dB point; -12 dB per octave) and then segmented into 1000 ms epochs beginning 200 ms prior to the onset of the critical distractor and target. Eye blink and eye movement artifacts were detected using a two-step procedure involving automated artifact detection to detect blink artifacts on channel AF3 and step-like artifacts on the HEOG channel followed by manual inspection of all epochs. Artifact-free epochs were then used for further analysis.

Results and Discussion

Behavioral data indicates that the emotional, but not neutral, critical distractors were able to capture attention robustly at a short lag between the distractor and target (as seen in Figure 3). Target discrimination accuracy at lag 2 was worse following an emotional image (mean = .62) than following a neutral image (mean = .75), with baseline performance being best (mean = .8). Importantly, task performance was similar at lag 8 regardless of whether the critical distractor was emotional (mean = .79) or

neutral (mean = .81), and in line with baseline target performance (mean = .78). This pattern of results is typical of an EAB paradigm and suggests the presence of an EAB.

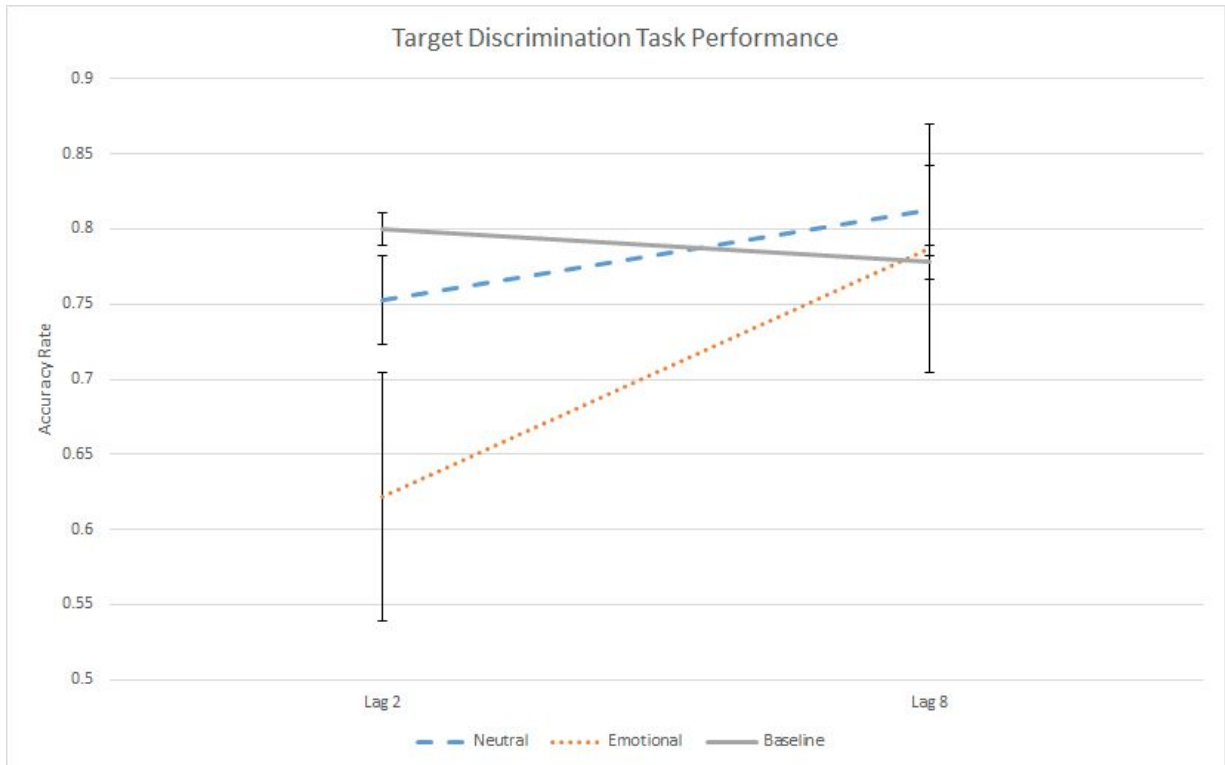


Figure 3. Chart of performance on target discrimination task. Participants performed worse when the target was closely preceded by an emotional as opposed to neutral target, but this difference in performance across affective conditions is negligible at the longer lag. This is a characteristic performance pattern indicative of the presence of an EAB to the emotional images.

In order to explore my hypotheses, I studied the differential electrophysiological activity between that elicited by the emotional and neutral critical distractors. The first of these hypotheses is that there would be changes in early sensory components as a function of the emotional nature of the critical distractors when the critical distractor prevented accurate target discrimination. Indeed, there is qualitative evidence that there was an enhancement of early positive activity in the occipital lobe (PO3, POz, and PO4) in response to emotional critical distractors when an incorrect target response was

given, regardless of lag between the critical distractor and target (see Figure 4). This may be evidence of the increased P1 magnitude in response to emotional images observed in previous experiments (Müller et al., 2008; Schupp et al., 2003). However, electrophysiological data from the same electrodes listed above do not appear to reliably demonstrate differential N1 magnitude to emotional images regardless of lag or target performance, which is not in line with prior research showing a general increase in N1 component related to affective content (Hajcak et al., 2012).

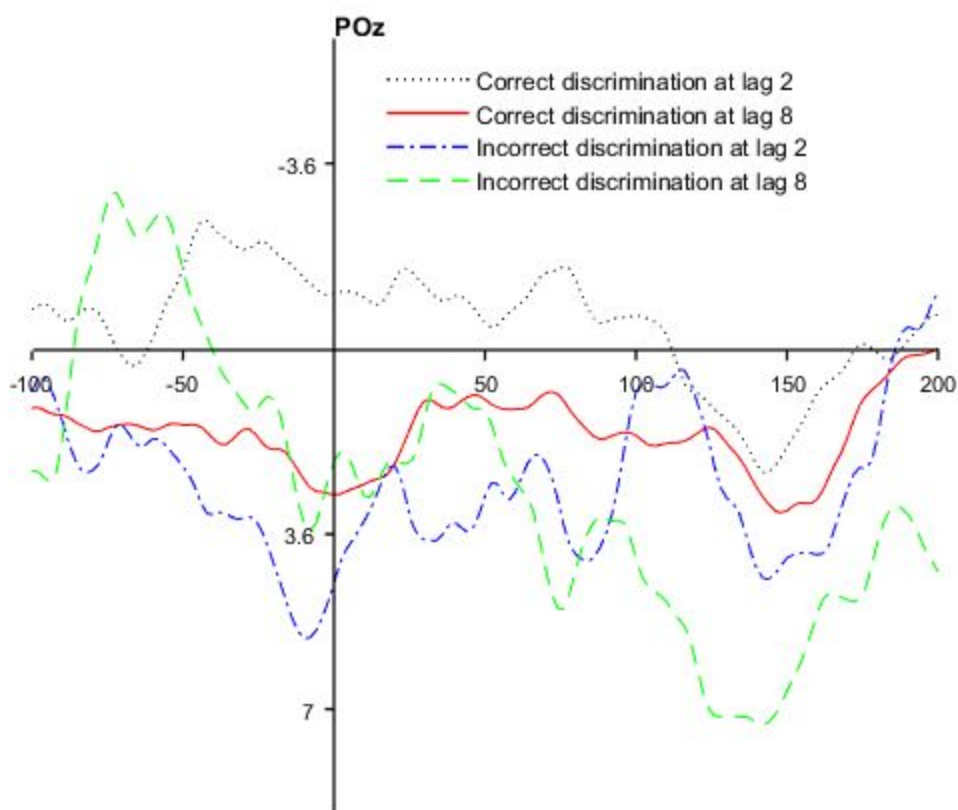


Figure 4. Differences waves computed by subtracting responses to neutral critical distractors from responses to emotional critical distractors, with the x-axis representing time from critical distractor onset and the y-axis representing difference in microvolts. Each of the lines is separated based upon the lag between the critical distractor and target as well as whether there was a correct target discrimination made on that trial. There is noticeably more positive activity in the time during which P1 is typically

observed (before 100 ms) in response to the emotional than neutral critical distractors, observed across every lag and target discrimination condition.

Additionally, it is apparent that emotional images elicited a greater negativity than neutral images beginning at approximately 200 ms from distractor onset regardless of lag or target accuracy, which may be evidence of a greater N2 to emotional images (see Figure 5). Due to the very general nature of this finding, this effect is not the result of interference from target onset and can generally be attributed to the deployment of selective attentional resources to the emotional critical distractor. As is evident in the portion of Figure 5 referenced by the black arrow, the magnitude of this negativity in response to the emotional critical distractor may have been predictive of target identification at lag 2, as there was a greater negativity in comparison to the presentation of neutral images when the target was not correctly identified as opposed to when it was correctly identified. Additionally, there was a lateral posterior positivity observed in the parieto-occipital electrodes characteristic of the exaggerated LPP observed in response to erotic images (Weinberg & Hajcak, 2010) that may have interrupted processing of the subsequent target. Finally, the P3 component in response to the critical distractor was significantly larger for emotional than neutral distractors. However, the magnitude of this difference did not vary reliably based upon target discrimination accuracy or lag, so this may represent general distractor processing rather than acting as an index of working memory consolidation in this case.

The present pilot study indicates that there is merit in pursuing a full EEG study of the Emotional Attentional Blink focusing on the stage of attention (or preattention) at

which the emotional distractor is prioritized for resources. Generally, it seems that the EAB paradigm could be a viable medium through which to study the temporal dynamics of top-down and bottom-up attention in the context of the EAB. More specifically, the present study clearly demonstrated differences in early neural activity associated with perceptual components (P1 and N1), indicating that the valence of these emotional images modulated early, possibly pre-attentive, neural processing. Furthermore, later attentional components typically associated with attentional selection (N2) and continued engagement of attentional resources (LPP) varied based upon the valence of the critical distractor and whether the participant was able to make a correct target discrimination. This suggests changes in underlying neural activity related to disruption of the top-down task by bottom-up attentional capture by the critical distractor. Should the present study be continued, it may be possible to more reliably relate these differences in distractor processing, related to distractor valence and target discrimination, to modulations of target processing.

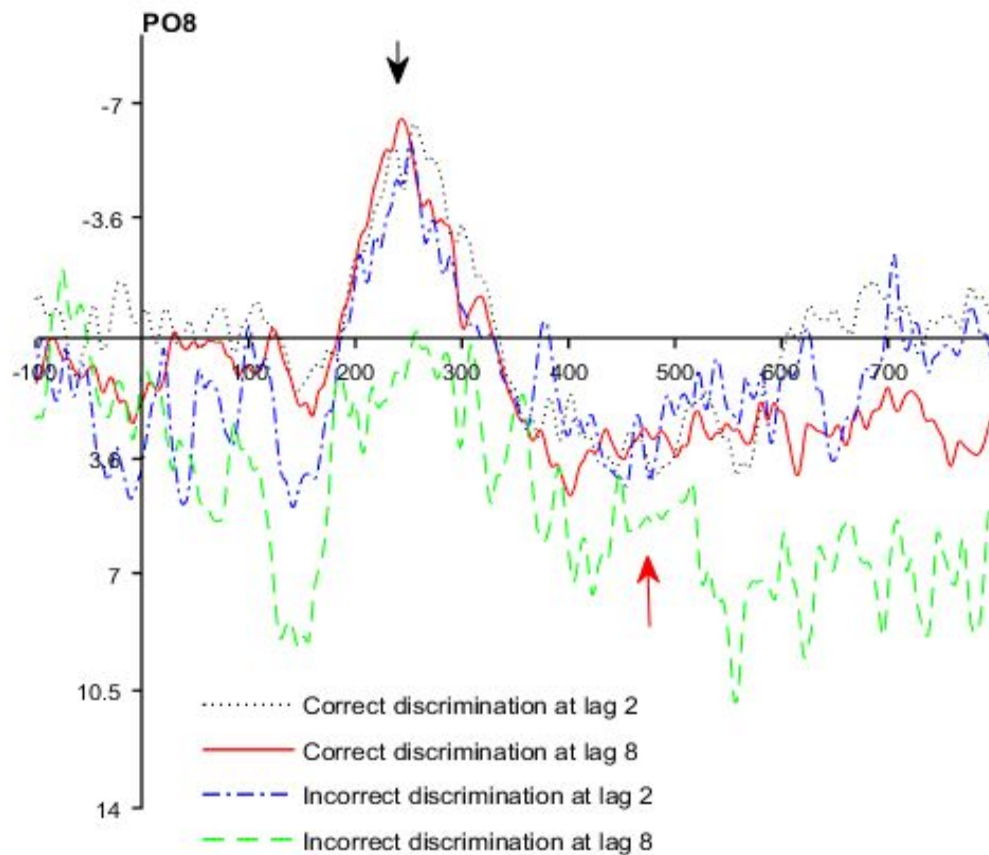


Figure 5. Differences waves computed by subtracting responses to neutral critical distractors from responses to emotional critical distractors, with the x-axis representing time from critical distractor onset and the y-axis representing difference in microvolts. Each of the lines is separated based upon the lag between the critical distractor and target as well as whether there was a correct target discrimination made on that trial. There is noticeably more negative activity (marked by the black arrow) in the time during which N2 is typically observed (between 200 and 300 ms) in response to the emotional than neutral critical distractors, observed across every lag and target discrimination condition. Additionally, there is a lateral posterior positivity observed (marked by the red arrow), characteristic of the extended processing of emotional (in this case, erotic) stimuli.

Experiment 2

Introduction

While experiment 1 may prove integral in discovering which stage of processing that the prioritization of emotional images occurs, it does not directly address whether

this prioritization is a result of the dual-stream model proposed in the review above. Accordingly, the present experiment attempts to implicate subcortical regions in this (possibly) preattentive process by utilizing a psychometric study. This route of research would be useful in developing more directly testable conceptual theories of how the EAB may arise, aiding the study of the neural bases of emotion as a whole and the EAB in particular.

Though we have previously encountered the concept of the dual-stream model in the context of endogenous and exogenous attention, it is important to note that there are less specific theories regarding the differences between the two pathways. In particular, animal and human studies suggest that the dorsal stream is responsible for the processing of low spatial frequency visual information as a result of its magnocellular input to and from subcortical structures (Schiller, Malpeli, & Schein, 1979) including the amygdala (Vuilleumier, Armony, Driver, & Dolan, 2003). Conversely, the ventral system is largely responsible for the processing of fine details as a result of its parvocellular input (Merigan & Maunsell, 1993). Unique from the dorsal stream, this ventral parvocellular stream does not send direct input to subcortical pathways (Hubel & Livingstone, 1988) thought to be responsible for the processing of emotional stimuli (Taylor & Fragopanagos, 2005; Tamietto & de Gelder, 2010).

This separation of a magnocellular system responsible for rapid low spatial frequency processing and a parvocellular system responsible for slower high spatial frequency processing presents an opportunity to study how the emotional critical distractors in the EAB may engage with subcortical structures. As previously noted,

these subcortical structures do not receive input from the parvocellular pathway. Therefore, manipulations of the spatial frequency of the critical distractor should allow for confirmation of the subcortical network's involvement in modulating perception of emotional stimuli.

The present study will utilize a modified EAB paradigm in which all images will be of faces. Modification of the paradigm is necessary in order to effectively accommodate manipulations of spatial frequency integral to the study, as more complex critical distractors of multiple persons may not maintain valence after spatial filtering. Using face stimuli offers a solution to this issue, as there is precedence for the salience and neural basis of emotional face processing from other experimental paradigms. Evidence from behavioral studies indicate that face stimuli consistently capture attention when displaying emotional facial expressions in behavioral cue-target (Phelps, Ling, & Carrasco, 2006; Bocanegra & Zeelenberg, 2009) and RSVP paradigms (de Jong, Koster, van Wees, & Martens, 2009; Stein et al., 2009). There are some clues as to the neural basis of this attentional capture. Face stimuli demonstrating an emotional facial expression differentially activate the amygdala based upon the spatial frequency of the stimulus (Kim et al., 2003; Kim et al., 2004; Whalen et al., 2004). Additionally, these emotional facial expressions preferentially activate the superior colliculus, pulvinar, and amygdala regardless of spatial frequency (Vuilleumier et al., 2003), supporting the idea of a subcortical pathway to the amygdala via the superior colliculus and pulvinar (Vuilleumier, 2005; Pessoa & Adolphs, 2010).

Though there has yet to be an EAB study utilizing face images as the experimental stimuli, it is possible to design an EAB paradigm in which all characteristics and demands central to the paradigm are maintained. Stimuli will all be relatively homogenous in low-level image features, the critical distractor will be distinguished by its emotional valence, and the task will involve a binary discrimination of a characteristic of the target. Distractors will be upright male and female faces, while critical distractors will be upright male and female faces exhibiting an expression of anger, happiness, or surprise. In separate blocks, these face images will be decomposed into their high spatial frequency (HSF) or low spatial frequency components (LSF), which should allow us to exploit the spatial frequency preferences of each pathway without affecting the emotional ratings of the critical distractor (Vuilleumier et al., 2003). Additionally, the target will be a neutral inverted face and participants will be asked to respond with the gender of the inverted target face. Stimuli filtering will be counterbalanced across three conditions in addition to valence: unfiltered, HSF filtered, and LSF filtered.

If subcortical structures are involved in the facilitation of emotional image processing, then a comparable EAB effect should be observed in the unfiltered condition and LSF filtered condition. In the HSF filtered condition, however, there should be an attenuation of the EAB effect as a result of a lack of parvocellular input to the subcortical structures theorized to be the generators of this effect. A different pattern of results would implicate more extensive processing pathways in the attentional capture by the emotional critical distractor. As a secondary pursuit, I will attempt to relate

differences in task performance to differences in the valence of the critical distractors, looking for a relationship between the magnitude of the EAB and the valence of the face. Because faces have never been utilized in the EAB paradigm, it is worthwhile to test whether findings relating distractor valence to EAB magnitude in the typical EAB paradigm may extend to the present.

Method

The experimental task will consist of a modified EAB paradigm, involving a rapid serial visual presentation (RSVP) of 17 images presented at fixation for approximately 100 ms each. All images on a given trial will consist of different upright male or female face stimuli except for two: the critical distractor and the target stimulus. The target, an inverted neutral male or female face, will be presented at a lag of either 2 or 8 images after a critical distractor (~200 ms or ~800 ms). The emotional critical distractor will be an image of a male or female face exhibiting a surprised or angry facial expression, whereas the neutral critical distractor images will be exhibiting a neutral facial expression. All images in a trial will be presented with one of three filter conditions counterbalanced across blocks: unfiltered, HSF filtered, LSF filtered (Vuilleumier et al., 2003). The extent of this filtering will be calibrated based upon a single target RSVP task similar to the experimental task, but without critical distractors. Spatial filtering in this calibration task will be adjusted until the participant is able to perform the task at an acceptable level. In the experimental task, participants will be asked to discriminate the gender of the inverted target face, with a keypress to indicate either male or female.

Discussion

The present study attempts to directly implicate a subcortical pathway responsible for emotional processing by taking advantage of the neural structures of the magnocellular and parvocellular pathways. Using a novel paradigm, it is possible to attempt to selectively engage the subcortical structures theorized to be responsible for the attentional capture of the emotional image. This is accomplished by presenting LSF information to activate the magnocellular pathway, which has projections to subcortical structures, and not the parvocellular pathway.

LSF information should engage subcortical areas and result in a persistence of the EAB equivalent to that observed in the unfiltered condition, observable as deficits in target accuracy. Conversely, HSF information should not be able to engage subcortical areas on the same timescale, which should lead to a diminished EAB if subcortical structures are responsible for emotional processing. A confirmation of this pattern of data would be indicative of a central role of subcortical structures in the modulation of attention by the emotional critical distractor. Furthermore, this would extend the study of the EAB by demonstrating that face images are also viable stimuli in the EAB paradigm.

There are several other possible results worth noting and interpreting. If there is not an observed EAB in the unfiltered blocks, this would be indicative of face images being inappropriate stimuli for use in the paradigm. If the EAB is instead not observed in either of the filtered conditions, then the spatial filtering may have prevented the affective nature of the face stimuli from being interpreted. Though there is evidence that the emotional content of faces persists through both HSF and LSF filtering (Vuilleumier et al., 2003), the valence of these faces may not fully reach awareness in both

conditions (Schyns & Oliva, 1999; Deruelle, Rondan, Gepner, & Tardif, 2004). Most importantly, if spatial frequency is not a factor in target performance then this would implicate both the dorsal and ventral pathways in the processing of emotional stimuli and suggest that subcortical structures do not modulate attention independently.

Experiment 3

Introduction

Within this research plan, I have addressed two of the most critical questions remaining about attentional capture by emotional images, with a focus on these questions in the context of the EAB. To begin, I explored whether the prioritization of emotional images occurs at a preattentive stage or a central bottleneck. Next, I addressed whether attentional capture by emotional images is the result of a subcortical system responsible for rapid attentional modulation. Both of these questions are central to what is the most far-reaching implication of the study of the EAB: the characterization of the dorsal and ventral pathways for endogenous and exogenous attention respectively. The present route of research is unique in that it allows for directly causal manipulation of neural activity, which allows for more powerful and concise conclusions. Unique to this approach, there is the opportunity to directly test the greater dual-stream model of attention by implicating the performance of the EAB task and manipulating areas associated with both the dorsal and ventral streams.

This study will attempt to causally implicate the aforementioned ventral stream in the attentional capture of the emotional critical distractor in the EAB paradigm in order

to advance the understanding of how these pathways may interact to create holistic changes in attention in response to emotionally salient stimuli. This will be accomplished by utilizing Transcranial Magnetic Stimulation (TMS), which creates magnetic fields that may be directed towards specific cortical areas to hinder or facilitate neural activity with surprising precision. With TMS, it is possible to create a temporary lesion in the ventral stream and observe the resulting changes in behavior on the typical EAB paradigm. A strong candidate for the location of this lesion is the right Temporoparietal Junction (TPJ), which is consistently identified as a lynchpin for the exogenous ventral stream necessary to the reorienting of attention to behaviorally relevant (but not task relevant) stimuli at attended locations, independent of the endogenous dorsal stream (Serences et al., 2005; Corbetta, Patel, & Shulman, 2008; Chica, Bartolomeo, & Valero-Cabre, 2011; Vossel, Geng, & Fink, 2014). As reviewed above, it has been suggested that the exogenous attentional pathway sends projections to the frontal lobe via a right hemisphere-lateralized ventral route through the temporoparietal junction (Corbetta & Shulman, 2002). This suggestion is further bolstered by the observation that right ventral brain damage in stroke patients is typically accompanied by spatial neglect and difficulty reorienting attention (Corbetta et al., 2005). By temporarily lesioning a critical portion of the ventral route, it is possible to both test this theoretical model and implicate the ventral stream in attentional capture by emotional images with interpretation of purely behavioral data.

A previous study that applied theta-burst TMS to the TPJ demonstrated resulting hemisphere-specific modulations of exogenous contingent capture (Chang et al., 2012),

with only right TPJ stimulation resulting in significant changes in attentional allocation. The contingent capture paradigm implicates both endogenous and exogenous attention, but is unique from the EAB paradigm in that it utilizes simple stimuli to study failures of spatial attention rather than temporal limitations (Belopolsky, Schreij, & Theeuwes, 2010). Therefore, there has yet to be a study utilizing TMS implicating the TPJ in non-spatial attentional capture, as would be predicted in the model proposed by Corbetta and Shulman (2002) and be tested in the present experiment.

If the lesioning of the right TPJ results in a decrease in emotional distractor processing, which would be indicated by improved target accuracy in the short lags of the EAB task, then it would be appropriate to conclude that the TPJ is indeed implicated in the ventral, exogenous attentional stream. If the application of TMS to the TPJ does not attenuate the EAB, then this would lend credence to several of the competing theories of emotional attentional capture.

Method

The present experiment will utilize the typical EAB paradigm, described in the method section of Experiment 1. Participants will perform three sessions for the experiment with a different TMS stimulation condition in each session, the order of which will be counterbalanced across participants. The three TMS stimulation conditions involve stimulation of the right TPJ (Talairach coordinate: 55, 44, 24), stimulation of the left TPJ, and a sham condition in which the TMS machine is not operating. The location chosen for TPJ stimulation is based upon previous imaging and TMS studies of the TPJ (Serences et al., 2005; Chang et al., 2010). TMS theta pulses will be applied in a

continuous rTMS pattern utilized by Chang et al. (2010) and verified as effective by previous studies of varying nature, meant to inhibit the TPJ.

Discussion

The present experiment attempts to directly implicate the theorized ventral stream in the exogenous attentional capture by the emotional critical distractor. This study has the potential to challenge the concept of a dual-stream attentional system mediating the interactions between endogenous and exogenous attention and more extensively document the functions of the TPJ. In the context of the EAB, this study may indicate possible neural mechanisms that give rise to the interruption of the top-down EAB task by the emotional critical distractor and further cement the EAB paradigm's role as an effective medium through which to study the intersection of the exogenous and endogenous systems.

If the TMS stimulation of the right TPJ results in improved target identification, it would causally implicate the TPJ in the attentional capture of the emotional critical distractor. Generally, this would support the notion that the EAB is the result of reflexive attentional reorientation resulting from activity mediated by the TPJ in the ventral stream, further suggesting that the EAB is the byproduct of an interaction between the dorsal and ventral streams. When this interaction is halted as a result of interrupting the ventral stream responsible for exogenous attention, the dorsal system is free to endogenously orient attention and perform the EAB's target identification task. It is important to note that this finding would not necessarily stand in opposition to results in experiment 2 implicating a subcortical system. Rather, this may support the idea that

the subcortical and ventral systems may work together to quickly reorient attention to emotionally salient stimuli through reemergent connections between the two systems (Pessoa & Adolphs, 2010).

The conclusions resulting from a failure to attenuate the EAB with TMS stimulation are much less clear-cut. This finding may indicate that the EAB arises from separate neural pathways, which would explain the lack of interaction with the TPJ. Alternatively, a null effect could demonstrate that the TPJ is not responsible for the reorienting of attention in the temporal dimension. This remains a possibility, as there is only evidence for the TPJ acting in the spatial domain in a contingent capture task, which is unique from the RSVP task utilized in the EAB paradigm. Finally, and most improbably, this could indicate that the TPJ is not a part of the theorized ventral pathway. Given the body of evidence to the contrary, it is unlikely that this is the case. Regardless of outcome, this study will contribute to understanding of the dorsal and ventral pathways and their respective roles in the orienting of attention.

Conclusion

The EAB is a robust attentional phenomenon that has the potential to be an effective tool in both clinical and cognitive psychological research. In clinical research, the EAB may serve as a measure of attentional disruption and intervention effectiveness. However, the possible applications of the EAB as a tool to study both endogenous and exogenous attention as well as emotion-specific processing are even more compelling.

The EAB paradigm may be adjusted and used in conjunction with research and neuroimaging methods to explore the neural mechanisms that underlie these psychological processes. In particular, the study of the EAB may prove integral in teasing apart the neural pathways responsible for both endogenous and exogenous attention in order to create more compelling models of holistic attention. The EAB paradigm creates a unique temporal conflict between top-down and bottom-up attention that makes it useful to this end. By studying the neural activity that underlies the EAB, it is possible to confirm or continue to revise the dual-stream model of attention that has been proposed extensively in neuroscience literature (Corbetta & Shulman, 2002).

Furthermore, the EAB paradigm may be utilized to more fully characterize models of emotional processing and its possibly subcortical bases (Taylor & Fragopanagos, 2005; Tamietto & de Gelder, 2010). Review of emotion literature has revealed that the variance in paradigms utilized in the subfield has prevented extensive and consistent testing of existing models of emotion, yielding confirmatory studies that generate little in novelty. Even those studies that utilize well-established paradigms, such as visual search (Müller et al., 2008; Ohman et al., 2010) and RSVP (Arnell et al., 2007) paradigms, do not control for individual differences in participant responses to valenced stimuli. Realistically, this may be a limitation of affective research as a whole, as it may not be possible to completely account for these differences. However, utilizing a consistent experimental paradigm is an effective initial step towards solidifying emotional research and building a framework through which to study emotion with fewer outstanding variables, as there is already extensive research on the EAB.

Therefore, integrating these subfields in the study of the EAB would be an effective approach to advancing the study of both attention and emotion. The paradigm of the EAB is compelling simple, as the RSVP stream offers a well-researched and flexible backbone for experimental design. Indeed, the RSVP paradigm has been established in several different subfields of cognitive study, offering precedent for a wide range of manipulations that may be incorporated in order to test models of both attentional systems and emotional processing. More extensive research of the phenomenon will yield a greater understanding of the mechanisms that underlie the EAB, which will strengthen the findings of prior studies as well as extend the experimental manipulations that are possible as knowledge is enhanced. The experiments proposed in the current paper, along with the pilot data collected in the present electrophysiological study, demonstrate how the EAB paradigm may be able to integrate findings from emotion and attention literature while addressing the shortcomings within both of these subfields. Therefore, there is significant merit in the more extensive utilization of the EAB as a medium through which to address both cognitive and affective research topics in the future.

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